Issued July 6, 1907.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 44.

MILTON WHITNEY, Chief.

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BY

CLARENCE W. DORSEY.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 1, 1907.

Sir: I have the honor to transmit herewith a paper entitled Reclamation of Alkali Soils at Billings, Mont., by Clarence W. Dorsey, of this Bureau. This paper details the general conditions of this part of the Yellowstone Valley as regards alkali and seepage water, and gives an account of the reclamation demonstration carried on near Billings on the O'Donnell tract. The results of the work at Billings have been very gratifying and, I believe, have resulted in awakening general interest in the question of reclaiming these alkali lands, both by the farmers privately and in cooperation with the State.

I recommend the publication of this report as Bulletin No. 44 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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RECLAMATION OF ALKALI SOILS AT BILLINGS, MONTANA.

INTRODUCTION.

Billings is situated in southeastern Montana, in a long, narrow valley characteristic of the lower Yellowstone River in the eastern part of the State. The valley is bounded on the north by sharp sandstone bluffs, rising from 200 to 500 feet above the valley floor. On the south in places bold bluffs of blue shale sharply define the valley or it merges into a mass of rounded hills that increase in height at greater distances from the river. The river occupies the lowest trough in the valley while successively higher terraces of low elevation give character to the surface relief of the valley. The terraces are marked by steep faces on the river side and extend as wide, level plateaus in places attaining a maximum width of 4 miles. They bear a definite relation to the course of the river and mark the various stages in the formation of the valley.

Billings has an elevation of 3,119 feet above sea level. The climate is characterized by extremes of heat and cold and an annual rainfall of about 15 inches, the greater part of which occurs during the spring and early summer months. The climate may be classed as typical of the great semiarid plains lying east of the Rocky Mountains.

At the time of the settlement of the valley only a very small proportion of the land showed any sign of alkali. The areas where alkali was plainly in evidence occurred in the eastern part of the valley and in occasional areas below the higher bench line. Near the present site of Billings and east to the river only alkali-resistant vegetation grew abundantly and there was sufficient alkali in places to form a crust. There were also other areas scattered throughout the valley that contained more or less alkali. With the construction of the Minnesota and Montana Improvement ditch in 1882 irrigation began, but the rapid settlement and development of the valley did not take place until 1890. About four years later, when large areas were under irrigation, damage from seepage water was first noticed. Some of the lower lands became too wet for cultivation and were given over to the growth of rushes and other water-loving plants. Other areas of water-logged soils appeared, increased

in size, and were abandoned when cultivation was no longer possible. Not only were the lands damaged by the rise of the ground water, but alkali also appeared in increasing quantities and proved more serious than the injury from excess of water.

This damage continued for many years and the situation appeared serious indeed. Many farmers abandoned their farms and moved to other parts of the valley where cheap lands could be obtained. In the last few years, however, the situation has become more encouraging and conditions at the present time are such that the farmers of the valley need no longer fear alkali. It has been found that the alkali is confined to certain well-defined areas and is not extending beyond the boundaries of these areas, which do not aggregate more than 10 per cent of the area of the entire valley. An active interest in the subject of drainage has resulted in the formation of drainage districts, and already several large drainage systems have been completed, with others contemplated in the near future. Besides this important work the reclamation of a tract of alkali land by the Bureau of Soils has shown that it is comparatively easy to restore the damaged lands to their former productiveness by methods well within the reach of the progressive farmers of the valley.

SOIL AND ALKALI CONDITIONS IN THE VALLEY.

The alkali situation was first called to the attention of the Bureau of Soils in 1897. In that year Professor Whitney spent a few days in making a rapid reconnoissance of the valley. He found that there was much uncertainty on the part of the farmers as to just what the conditions in the soil were. It was then decided that a more thorough study of the valley should be made, to determine, if possible, the conditions in the soil, the possible results if present methods were continued, how to prevent the spread of alkali, and what should be done to reclaim the already abandoned lands. Such an investigation was made in the summer of 1898 by Mr. Thomas H. Means, and the results were published as Bulletin No. 14 of the Bureau of Soils.

RESULTS OF ALKALI STUDIES MADE DURING 1898.

Concerning the source of the alkali it was found that the farmers had advanced many theories and there was widespread belief that the alkali flats could probably be reclaimed by flooding the surface during a dry season and washing the crust off. Determinations of the amount and location of the alkali in the soil plainly showed that the crust contained only a small proportion of the alkali and that such a method would be inefficient. In every case of injury to crops that was examined it was shown that the first trouble was an accumulation of seepage water near the surface, and, while the water did not contain excessive quantities of alkali at first, continued evapora-

tion resulted in concentrating sufficient alkali at the surface to injure crops.

An examination of the structure of the valley showed that it had been carved out of sandstones and underlying shales. The sandstones that rise abruptly above the valley on the north are porous and carry small quantities of magnesium and sodium sulphates, which frequently appear as a white incrustation on the bare rock surface. The soft blue shales forming the boundary of the valley on the south are penetrated by numerous fine cracks and joints filled with fibrous gypsum, while larger cavities carry gypsum and calcium carbonate. Throughout the mass of the shales are found large quantities of sodium and magnesium sulphates, which form a white incrustation on the surface.

The soils of the valley were found to have been formed from the weathering of these shales and sandstones, modified and deposited by stream action. So it would appear that the rocks are directly responsible for the soluble salts contained in the soils, these salts consisting principally of sodium and magnesium sulphate. The sandy soils occurring in the valley have been derived largely from the sandstones, and hence contain originally less salts than the heavy soils that have been derived from shales.

A detailed study was made of sec. 2, T. 1 S., R. 25 E., and maps were prepared showing the alkali and underground water conditions. These maps clearly showed the relation of seepage waters to the accumulation of alkali and how essential such a study is to the proper understanding of the question of providing remedies to check further damage. A study was also made of the quantity of salts being removed by a drainage ditch surrounding the town of Billings, which had been constructed to intercept the seepage waters from higher irrigated lands. From this it was found that the flow of water in the ditch was about 40 second-feet and that about 16½ tons of salt per hour was being removed; that is, it was rapidly carrying away the alkali seepage waters, thereby checking the concentration of alkali in adjoining lands.

The investigation further showed that before irrigation the salts were present, but so evenly distributed throughout the soils that they were not injurious to crops. The injury was found to be due to overirrigation, to the translocation and local accumulation of salts by seepage waters, to the imperfect drainage facilities in the clay soils, and the inability of the soils to remove the excess of salts and seepage waters. It was pointed out that the only way to prevent the final abandonment of the land containing alkali was to provide underdrainage systems to carry off the excess of water and the

crops were negligible. Eighteen thousand six hundred and twenty-four acres contained from 0.20 to 0.60 per cent of alkali (2,000 to 6,000 parts per 1,000,000), and while the damage due to alkali was not great, in case all of the alkali became concentrated in the upper layers of soil injury would undoubtedly result. An area of 5,568 acres contained from 0.60 to 1.0 per cent of alkali, which is a little too much for the crops generally grown in the valley. Only 1,344 acres contained more than 1 per cent of alkali, and in their condition at that time (1902) were of little agricultural value. From these figures, representing the various grades of alkali, as well as from an inspection of the small sketch map, it will be seen that only about one-tenth of the area contains sufficient alkali to be a serious menace to crops.

In general it was found that the vertical distribution of the alkali is governed by the texture of the soil and subsoil and by the position of the soil and subsoil. In uncultivated areas of clay soil where alkali occurs its distribution below the first foot is quite uniform, the maximum quantity being found generally at a depth of 5 feet. Where the soils are heavy clay but have lighter subsoils the maximum alkali content is in one of the upper 3 feet of soil, but less alkali is found in the lower depths, the quantity depending largely upon the height of the ground water. In the deep clay soils where irrigation has been judiciously carried on the greatest quantity of alkali is found at a depth of from 3 to 6 feet. On some of the wide, level terraces and lower alkali lands along the river there is generally a surface accumulation of alkali with the maximum salt content in the first or second foot. In these localities the ground water is quite near the surface and within easy reach of the upward capillary power of the soil.

Above the canal in the sandy soils that have not as yet been irrigated little or no alkali was found in the soil to a depth of 6 feet, but moderate quantities were usually encountered at 7 and 8 feet, generally increasing with the depth. The alkali in the alluvial sandy loams found along the Yellowstone has resulted from evaporation of seepage water from higher lands. As before noted, the alkali in the higher bench and terrace soils has been derived directly from the breaking down of the sandstone and shale rocks, especially the latter, which are rich in soluble salts.

The general distribution of the larger alkali areas bears a direct relationship to the topography of the valley. As has been stated, the valley floor is marked by wide terraces, with a sharp bluff of from 15 to 30 feet emphasizing the line of demarcation between the different terraces. The outer or southern edge of these terraces is almost invariably higher than the central portion, and in places is even higher than the northern part. As a result of these topographic conditions, the depressions first became swampy as overirrigation was

practiced on the higher soils. The irrigation water, as it slowly soaked through the soil, dissolved the salts and carried them to the troughlike depressions. Evaporation of much of this water concentrated the salts, and these swampy areas were finally abandoned as alkali flats. The poor underdrainage of the clay soils has materially hastened this process of converting water-logged lands into alkali swamps.

The following table contains analyses of samples of alkali crusts and soils. The samples are typical of the alkali found in the soils in the Yellowstone Valley. It will be noticed that sodium sulphate predominates, with much smaller quantities of calcium and magnesium sulphate. The chlorides and bicarbonates are present only in small amounts, with traces of alkaline carbonates.

Chemical analyses of salts of typical alkali crusts and soils of the Billings area.

Constituent.	6600. Near NW. corner sec. 2, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6601. Center sec. 10, T. 1 S., R. 26 E., soil 0 to 10 inches.	6602. Center sec. 10, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6603. S. center sec. 9, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6604. Center sec. 8, T. 1 S., R. 26 E., crust 0 to 1 inch.	6605. W. center sec. 34, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.79	2.99	0.16	3.63	4.14	1.85
Magnesium (Mg)	1.79	.85	.24	2.01	2.57	2.95
Sodium (Na)	28.16	20.56	31.73	23.51	22.06	25.03
Potassium (K)	.72	9.63	.88	2.78	2.79	1.08
Sulphuric acid (SO_4)	67.73	45.85	59.93	62.98	61.06	66.49
Chlorine (Cl)	.33	Trace.	1.48	3.24	4.70	1.54
Bicarbonic acid (HCO_3)	.48	16.06	2.83	1.85	2.68	1.06
Carbonic acid (CO_3)	Trace.	4.06	2.75	....	....	....
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	2.71	10.07	.55	12.29	14.00	6.08
Magnesium sulphate ($MgSO_4$)	8.90	4.06	1.22	9.91	12.76	14.58
Sodium sulphate (Na_2SO_4)	85.57	35.12	85.06	66.66	55.68	72.93
Potassium sulphate (K_2SO_4)	1.60	21.41	1.96	6.18	6.15	2.41
Sodium bicarbonate ($NaHCO_3$)	.67	22.06	3.90	2.55	3.69	1.46
Sodium carbonate (Na_2CO_3)	Trace.	7.28	4.87	....	....	....
Sodium chloride (NaCl)	.55	Trace.	2.44	5.41	7.72	2.54
Per cent soluble	41.68	.934	17.00	2.59	1.79	9.04

It is the exception to find in an arid country alkali consisting mainly of sodium sulphate; in most cases sodium chloride is the predominant constituent. As compared with the type of alkali found in other districts, the Billings type is generally supposed to be the least injurious to field crops. Some determinations as to its effects on crops were made in the different years during which the Bureau studied the alkali conditions in the valley, as well as in 1906, when the reclamation work was in progress. From the following statements it will be noticed that in general the crops are able to withstand more alkali than in areas where sodium chloride or the more toxic sodium carbonate prevails.

Although 1906 was the first year in which sugar beets were grown, it seems that they are the most resistant crop to alkali that is grown in

the valley. Fields were found where the beets were growing in from 0.60 to 1 per cent of alkali, while the surface foot contained nearly 1 per cent. Alfalfa, after it has become well established, comes next in resistance, as it has been found in good condition in soil averaging a little over 0.60 per cent. In one place, where the water table was about 4 feet below the surface, alfalfa was in poor condition, with an average of 0.50 per cent of salt present. Oats have been found growing in soil containing 0.85 per cent and 0.91 per cent of alkali, as averages for 6 feet. The plants in both cases were small and weakly, and were only surviving. These limits are, of course, too high to be taken as a guide for the resistance of this crop, but shows how much salt can be tolerated by some individual plants. Good oats were found growing in soil with 0.58 per cent as an average for 6 feet and with no surface accumulation. Only one field of wheat was noticed where there were alkali spots. At the edge of these spots, where the wheat was dying, the soil averaged only 0.20 to 0.40 per cent to a depth of 6 feet, with 0.55 per cent for the surface foot.

A comparison of the conditions in selected areas in 1902 with the conditions existing in 1898 showed that the alkali accumulations were becoming more pronounced. This was particularly brought out by a study of sec. 2, T. 1 S., R. 25 E., which had been given special attention in 1898. By using the same method of alkali determination (the electrolytic bridge) it was found just what changes had taken place in the intervening period. In 1898, of the entire section (640 acres) only 186 acres contained alkali in what may be considered injurious quantities, while 454 acres contained some alkali, but not enough to damage crops. In 1902 it was found that the area of land containing much alkali had increased to 506 acres. Again, in 1898 it was found that the greatest concentration of alkali in the first foot of soil did not exceed 1 per cent, and there were only 13 acres containing from 0.60 to 1.0 per cent to a depth of 6 feet, but in 1902 there were 224 acres with from 0.60 to 1.0 per cent and 128 acres containing more than 1 per cent. This is a striking example of the manner in which alkali has continued to accumulate on a given tract of land where no remedial measures had been adopted. In 1906 the alkali conditions were studied again over the entire valley to ascertain the changes, if any, since 1902. It was found that the area affected by alkali had about reached its maximum limit; that is, the increase in land damaged by alkali was very slight in the four years that had elapsed since the survey was made in 1902. This study clearly brought out the fact, however, that the concentration of alkali in the well-defined alkali areas is increasing rapidly. Localities that in 1902 were only slightly damaged by alkali have since been abandoned because the land is no longer capable of producing crops. While this is a serious matter to those owning lands containing alkali, the

knowledge that the possible limit of spread has been reached is gratifying for the entire valley.

RECLAMATION OF THE O'DONNELL TRACT.

In 1904 the Bureau undertook the reclamation of a tract of alkali land in the Yellowstone Valley. This was in line with the policy of the Bureau, namely, to establish demonstration experiments in reclaiming alkali land in different areas where a soil survey had clearly defined the alkali problem. The reports made by the Bureau in 1898, as well as in 1902, plainly showed the cause of the trouble and the way of attacking the question, and stated, moreover, that conditions in the valley were very simple as compared with other irrigated districts. In order, then, to demonstrate the principles in reclaiming alkali land, a tract of land 1 mile west of Billings was selected for the experiment. The tract was within easy reach of Billings and near one of the prominent roads of the valley, a location where the progress of the work could be observed by those interested. Pl. I, fig. 1, shows the condition of the land as it appeared when selected by the Bureau of Soils. No useful crops had ever been grown on the land, although one or two attempts had been made a score of years ago. There were many places covered with a thick crust of alkali, while other parts of the tract supported a scattering growth of greasewood, salt grass, and bunches of prickly pear cactus.

In texture the soil varies from a sandy loam to a stiff clay, locally known as gumbo. The clay soil is sticky and difficult to cultivate and so impervious that water percolates through it very slowly. In places at a depth of several feet gravel is found, which is often firmly cemented together and is well-nigh impervious to water. An alkali survey of the tract gave the following results: Fourteen acres, nearly three-fourths of the tract, contained more than 1 per cent of alkali to a depth of 4 feet; 4.2 acres contained from 0.60 to 1.0 per cent, and 1.6 acres carried from 0.40 to 0.60 per cent of alkali. The maximum alkali content was found in the first foot and usually decreased downward. Where the soil consisted of heavy clay the greatest amount of alkali was found. The alkali was typical of that found in other parts of the Billings area. It consisted mainly of sodium sulphate, with smaller quantities of magnesium and calcium sulphate, traces of chlorides, and bicarbonates, but no traces of carbonates. The ground water in midsummer stood within 4 or 5 feet from the surface and carried over 2 per cent of soluble salts.

On account of the large quantities of alkali present and the slow movement of water through the soil a drainage system was considered necessary to achieve marked results within a reasonable time. An outlet was easily secured by digging 660 feet to the drainage

ditch that surrounds the city of Billings. The question of securing tiles for the drainage system proved more troublesome. When it was found that no tiles could be purchased near at hand, an effort was made to interest a local brick company in manufacturing tiles. This resulted in the purchase of a tile machine and the contract was awarded to this company. There had always been a small demand at Billings and near-by points for drain tiles and it was believed a much larger demand could be created if the tiles could be sold at much lower prices than those purchased at distant points. By mixing weathered shale with the ordinary brick clay it was found that a satisfactory tile could be made. After making several hundred feet of tiles the tile machine was broken and no further effort was made by the brick company to fulfill their contract. The Bureau was then forced to purchase tiles from Kansas City, Mo., which greatly delayed the installation of the drainage system. The accompanying

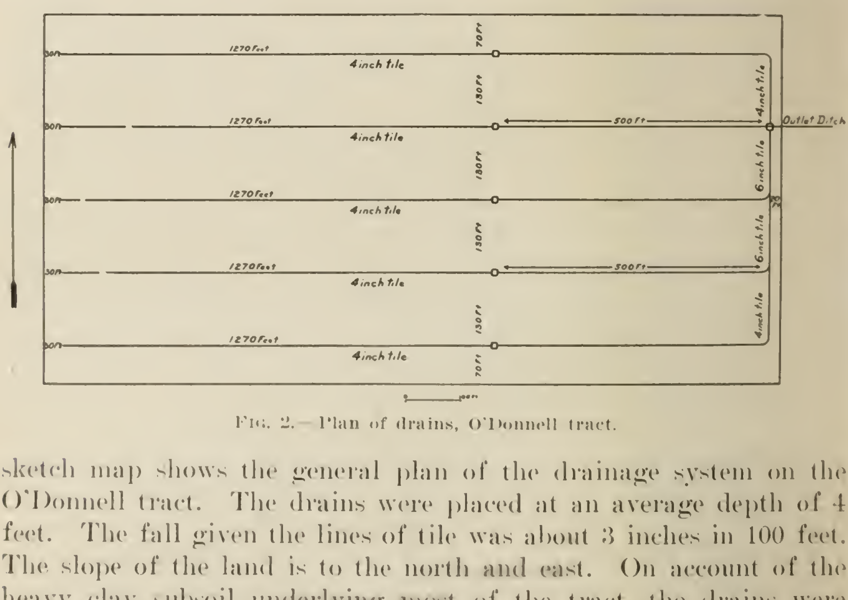

FIG. 2.—Plan of drains, O'Donnell tract.

sketch map shows the general plan of the drainage system on the O'Donnell tract. The drains were placed at an average depth of 4 feet. The fall given the lines of tile was about 3 inches in 100 feet. The slope of the land is to the north and east. On account of the heavy clay subsoil underlying most of the tract, the drains were placed at intervals of 130 feet. The five laterals consist of 4-inch tiles, with silt catchment basins placed 500 feet from the eastern end of each lateral. From the junction of the laterals the outlet drain consists of a box open on the bottom placed at an average depth of 5 feet. Registering weirs were placed at the outlet of the drainage system and at the point where the water-supply canal enters the western end of the tract.

The cost of installing the drainage system was approximately $35 an acre. This excessive cost was occasioned by the cost of the tiles purchased at a distant point and by the dry compacted clay soils,

FIG. 1.—SHOWING BARREN ASPECT OF THE LAND INCLUDED IN THE O'DONNELL TRACT BEFORE RECLAMATION.

FIG. 2.—SHOWING HEAVY STAND OF OATS ON THE SAME TRACT AFTER ONE YEAR'S TREATMENT BY THE UNDERDRAINAGE-FLOODING METHOD OF RECLAIMING ALKALI LANDS.

which made digging the ditches painfully slow. It is believed that with tiles sold by local factories at reasonable prices and by excavating the trenches, in the spring, when there is more moisture in the soil, the cost of drainage for most of the Billings area will not exceed on an average \$15 to \$20 an acre. The drainage system was completed too late in the season of 1904 to carry on flooding. The tract, however, was carefully leveled and checks thrown up to hold the water on the land. Fall plowing was also resorted to in order to leave the soil in an open and loose condition so that winter rains and snow might readily enter.

The early spring of 1905 was remarkable for the exceptionally heavy rainfall. It undoubtedly played an active part in effecting the reclamation of the O'Donnell tract. With the beginning of the heavy and continued rains the drains at once responded and by the latter part of June the abnormal rainfall had materially reduced the alkali content of the tract. From early in July until the end of September the tract was submerged practically all of the time. By an adjustment of small supply canals the water was allowed to run night and day and the checks were continually filled. There were two short periods when there was a scarcity of water and the tract was not flooded, but these were not long enough to allow the alkali to accumulate at the surface.

At the end of September, 1905, the soil was allowed to dry and an examination was made to determine the changes that had taken place in alkali content of the tract. It was found that there still remained in the soil only about one-seventh of the alkali that was originally present. An alkali survey made in June, 1905, after the heavy spring rains showed that the maximum alkali content was in the second and third feet, but at the close of the flooding operations in September the maximum was almost uniformly in the fourth foot. During the flooding period sufficient water was used to cover the entire tract to a depth of 6 feet, while the rainfall during this same period was only 1.37 inches; the evaporation was estimated at 12 inches from a free water surface. About one-half of the water used in flooding passed over the outlet weir at the point where the outlet ditch empties into the Billings drainage ditch, 660 feet east of the reclamation tract. A large part of the water undoubtedly passed into the country drainage of the tract or along the line of the outlet ditch. Tests of the drainage water made during the flooding season showed that the soluble salts decreased from 9,000 parts to 3,250 parts per 1,000,000. At the close of the season the tract was plowed and harrowed to overcome as far as possible the bad effects of the continued flooding.

Early in the spring of 1906 the soil appeared to be in excellent

condition. The surface indications showed no traces of alkali, except along the north side of the tract, where no flooding had been carried on. An alkali survey showed even less alkali than had been found in September of 1905. In May the soil was disked and harrowed preparatory to seeding oats. The soil responded nicely to this treatment and an excellent seed bed was obtained. Russian side oats were planted May 16 and made rapid growth. A heavy stand was secured that compared favorably with crops sown on alkali-free soils in various parts of the valley. Severe wind and rain storms, however, considerably damaged the crop at the ripening period. The crop was harvested the last of August. Pl. I, fig. 2, shows the appearance of the tract a few days before the crop was cut. The yield was 44 bushels an acre, making the return for the 15 acres amount to $260. Considering that no crops had ever been grown on this land, the results obtained the first year after flooding were very gratifying. They showed conclusively that the removal of alkali had been most thorough and that the land was now in condition to grow any crop adapted to the climatic conditions of the valley.

At the time the crop was removed the tract was returned to the owners. It was the original intention to leave the reclaimed land with a satisfactory stand of alfalfa upon it, but the rapid extension of Billings made the land highly desirable for building purposes. The owners therefore subdivided the tract and sold it for residence purposes, except two lots which were reserved for vegetable gardens.

PRIVATE EFFORT IN RECLAIMING ALKALI LAND.

Prior to 1904, the year in which the Bureau undertook the reclamation of the O'Donnell tract, but little effort was made either to reclaim alkali lands or to utilize them in any way. Generally when the land accumulated sufficient alkali it was abandoned to salt grass and greasewood and valued only for the scant pasturage it afforded. Even during the period when the area of alkali was fast increasing, the farmers, while deploring the injury to their lands, seemed unable to adopt any preventive measures. Many whose lands were ruined moved elsewhere and took up new land, as they could easily do while prices remained low. A few farmers, it is true, tried to cultivate those portions of their farms damaged by alkali by plowing in the fall and seeding to oats the following spring. But the invariable result was that the land did not produce enough grain to pay for cutting and thrashing.

Some few farmers dug shallow ditches to remove the seepage water and some of the alkali, but the ditches were not deep enough and were soon allowed to fill up again, so that no beneficial results were accomplished. Within the last two years, however, considerable progress has been made in taking means to remove alkali from the

lands or to prevent conditions from becoming worse. In the summer of 1905 two drainage systems were installed. A bill has also been passed providing for the formation of drainage districts and county officers to look after such matters. By the enactment of this law it is possible for persons owning damaged lands to unite and constructs drains with outlets. Before the passage of this law it was not always possible to do this, as there was no way of securing an outlet through another man's land unless the owner gave his consent. As a result of this law one large district was completed and active steps were taken to form others. In addition to these districts formed under the provisions of the State law, considerable work is being done by groups of farmers cooperating to improve their land. On account of the interest manifested on every side by the farmers in the subject of drainage the prospects are very bright in the Billings area.

With the definite knowledge that alkali is not rapidly encroaching on new good soils and with the question of drainage for the largest areas affected by seepage water and alkali attended to, it now remains for the individual farmer to free his own particular land from alkali. This will require considerable effort, for some tracts of alkali land included at the present time within the drainage districts are situated long distances from the main drains. In a region of sandy subsoils and good underdrainage reclaiming alkali soils may be accomplished with but little effort, but it is unreasonable to suppose that heavy clay soils can be freed from excess of water and alkali by a deep main drain fully one-half mile away. This was clearly proved by the history of the O'Donnell tract reclaimed by this Bureau. The eastern end of this tract was only 660 feet from a deep ditch which had been dug prior to 1898, yet in 1904 this part of the tract contained the greatest quantity of alkali. From this it may be inferred that while the drainage ditch removed the excess of water from this part of the tract and perhaps checked the further accumulation of alkali it did not remove alkali from the upper layers of soil. This was not accomplished until a drainage system had been installed and copious flooding resorted to for several months. And so in many parts of the valley, after the district drainage systems have been constructed, in order to remove any considerable quantity of alkali it will be necessary to provide drainage for individual tracts of land. On the heavy soils having clay subsoils to a depth of several feet it will be advisable to place the drains at a good depth, say 4 or 5 feet, at intervals of about 150 feet apart. After this work has been completed the land should be flooded until it is believed shallow-rooted crops can be grown. For the small field drains tiles may be used in case they can be secured at reasonable prices, or boxes made of boards or planks, or, in case these prove

expensive, open ditches will prove effective if cleaned as often as may be necessary.

From the experience of the Bureau on the O'Donnell reclamation tract even the heaviest clay soils of the valley may be freed from alkali by flooding during the irrigating season, after an efficient drainage system has been installed. When the soils contain only moderate quantities of alkali in the areas where drainage districts have been found drainage of individual fields may not be necessary. If some crop that will tolerate some alkali, such as sugar beets, can be started and the soil has fair subsoil drainage each irrigation will remove a certain proportion of the salts, and eventually the field will be entirely reclaimed. Undoubtedly there are many areas in the drainage districts where the conditions of alkali and subsoil drainage are such that the land can be reclaimed in this manner. Deep plowing of the soil and liberal applications of water will materially hasten the reclamation of such tracts, as well as any course of treatment that will check surface evaporation and allow the ready percolation of water through the soil.

SUMMARY.

The soils of the Yellowstone Valley, in which Billings is situated, are mostly heavy loams and clays, which in their natural state contained large quantities of salts, especially in the lower depths. The origin of these salts is in the shales and sandstones, which upon weathering have formed the soils of the valley.

In the early development of the valley the areas visibly affected by alkali accumulations were small and attracted little attention. With extensive irrigation certain tracts of land became wet and swampy, gradually accumulated alkali, and finally were abandoned.

This damage from seepage water and alkali was clearly the result of overirrigation on heavy soils having very poor natural drainage. For a number of years the area of damaged lands spread rapidly, and conditions were considered serious by the farmers of the valley, and many moved to other places rather than combat such unusual and formidable problems.

An examination in 1898 by the Bureau of Soils showed that the deep subsoils were rich in salts, that shallow drains would be ineffectual, and that washing the surface only removed the accumulated alkali from a shallow depth of soil. It was pointed out that underdrainage to be effective must be deep, and that irrigation water should be sparingly used to prevent ruining lands at lower levels. Subsequent studies of the soil and alkali conditions of the valley in 1902 more clearly defined the problems and showed that the area of damaged lands was yearly increasing, and that it was imperative

for the farmers to adopt measures to prevent widespread injury to some of the finest tracts of land in the valley.

The experiment in reclaiming a worthless tract of alkali land by deep underdrainage and surface flooding, conducted by the Bureau of Soils, proved successful, and after one year's treatment a good crop of oats was harvested. This work showed the farmers just what steps were necessary to reclaim damaged lands and undoubtedly helped to arouse an interest in the subject.

At the present time the outlook in the valley is most promising, owing to the widespread interest manifested in the formation of drainage districts in the areas most severely damaged by excess of seepage waters and alkali. The State drainage laws make it possible for farmers to construct large drainage systems, and such work is progressing rapidly, while groups of farmers are closely cooperating to the same end.

With the subject of regional drainage so adequately provided for, the reclamation of small farms or individual fields will follow as soon as the farmers appreciate the necessity of further effort in addition to the larger remedial measures that have been adopted. In some cases this will consist of the thorough drainage of fields, using the main drains as an outlet and leaching the alkali from the soil by surface flooding. In other cases careful cultivation and irrigation of crops not especially sensitive may be depended upon to remove the small amount of salt contained in the soil.

In whatever way the alkali soils may be finally reclaimed, the people of the valley are certainly to be congratulated upon their commendable enterprise in so promptly undertaking measures to check the ravages of seepage water and alkali. It is an excellent example and one that should be followed by many other districts in various parts of the West.

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